Superconducting Magnetic Energy Storage

Principle

Superconducting Magnetic Energy Storage (SMES) is a conceptually simple way of electrical energy storage, just using the dual nature of the electromagnetism. An electrical current in a coil creates a magnetic field and the changes of this magnetic field create an electrical field, a voltage drop. The magnetic flux is a reservoir of energy. Superconducting wires do not deliver energy when conducting a current, so a coil made with that materials maintain the current and the magnetic flux can be stored. The magnetic flux is a reservoir of electrical energy. As shown in Figure 1, the energy is stored/delivered when a controller changes the current, increasing or reducing it, a voltage appears in the terminal which is regulated by the rate of change of the current, and can be adjusted by the regulator delivering or catching energy to or from the external circuits [1]. A cubic meter of magnetic flux with a density of 10 T has an energy of 40 MJ (11 kWh), the same than 40 m^3 of water at 100 m high. SMES coils should be made with superconducting wires and they require to be cold, very much cold. Typically, under 60 K even down to the liquid helium temperature (4 K) depending on the materials employed: High-Temperature Superconductors (HTS) or Low-Temperature Superconductors. The new scope for SMES is just using HTS at temperatures in the range of 30-40 K.

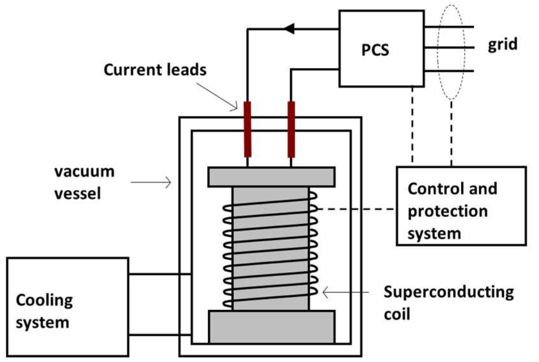

Figure 1. Schematic representation of a SMES system, including the Power Conditioning System (PCS), cryogenics and control and protection system, besides the superconducting coil. Adapted from [1].

Characteristics

SMES offer several advantages, when comparing to other technologies, namely:

Main applications

- Power quality at the customer or generator side.
- Voltage control and reactive power compensation.
- Improve transient stability of the grid.
- Uninterruptable Power Supply (UPS).

General performance

Typical Power: 100 kW to 10 MW

Cycle efficiency: 95%

Discharge time: ≥ minutes-hours

Response time: 5 ms

Cycle life: no degradation

Technical lifetime: 30 years

Maintenance: each 20-30 khours

- High round trip efficiency: 90-95%.
- Long lifetime: 30 years [2].
- High power, only limited by the electronics and electrical isolation.
- Ready to operate: in a few ms.
- Very robust: can be overloaded as much as the electronics allows.
- Very flexible for hybridisation: can be included in an electronic buffer with any other large capacity energy storage system improving their availability speed and their peak power.
- Symbiosis: SMES can take advantage of external resources as cooling in industrial polygons, hospitals, liquid nitrogen carriers, etc. It allows reducing the cooling and HTS wire investment cost and enhancing its efficiency.
- Environmentally friendly: specific geometries drastically reduce the stray field bellow any determined level. SMES do not use materials complex for recycling.
- No critical raw materials: only uses standard structural materials and HTS only require two tens of gram/km of Y or Gd, which are not dispersed and can be recovered after 30 years of service.

Maturity Level

SMES based on Low-Temperature Superconductors (LTS) have been built up to a power of 10 MW and a capacity of 20 MJ [3]. Qualified LTS SMES systems have shown in several field tests that they can fulfil all technical requirements and in the past, a few companies started to offer LTS SMES commercially. Due to the relatively high system cost, LTS SMES could not find a market up to now. Based on this history the maturity of LTS SMES has reached TRL level 8 which means that several systems were completed and

Figure 2. 10 MVA/1 s SMES at Kameyama field test, in Japan. Image from [4].

qualified through test and demonstration, even for large Energy-to-Power ratios, which are beneficial to reduce investment cost. Since 2011 three LTS SMES units with deliverable power of 10 MW are in operation Japan for bridging instantaneous voltage dips of critical industrial customers [4].

The discovery of HTS materials and the ongoing development of the 2G superconducting wires, the so-called coated conductors open a window for a new class of HTS SMES to work at higher temperatures up to 50 K, higher magnetic flux densities up to 20 T and even higher efficiencies.

The success in the production of HTS wires and tapes with an increasing number of producers and a decreasing cost-performance ratio envisages that a modular MW class HTS SMES could be an attractive device. Up now, 2.5 MW HTS SMES have been designed [2] which means that TRL level 5 to 6 has been reached with HTS SMES. Further improvement towards larger magnetic flux density systems, coil manufacturing, HTS winding cable and cooling simplification is ongoing.

Hybrid energy storage systems based on a SMES in combination with other storage technologies have been studied for different combinations [5]–[7] but not more than a proof of concept and small laboratory experiments on a TRL level 3 have been performed. Nevertheless, this seems attractive because it combines the benefits of a SMES with large storage capacity.

Maturity Level:

Installed rated power worldwide: 325 MW

Installation costs: depend on E/P ratio 300 €/kWh (E/P=4) to 2000 €/kWh (E/P=0.25)

Operating costs: 2 - 3% investment + cost of energy inefficiencies

Potential, barriers and challenges

- Improve critical material properties of HTS and MgB_2 tapes. This includes higher in-field current densities, lower AC and ramping losses, optimized wire architectures, longer lengths of high quality, high amperage conductors and cost reduction.
- Improve the modelling tools for a better design, optimising the costs and reliability of the SMES systems from the mechanical, thermal and electromagnetic point of view.
- Develop SMES related system technology with a focus on new concepts in magnet design, standardised components for cooling systems, cryostats and low loss current leads.
- Develop low-temperature heat rejection cryocoolers for working between 120-30 K with cooling power in the range of 100's of W, able to work with cryogens at 120 or 77 K as high temperature, thus allowing the use of LCH_4, LN_2 or LO_2 as a first cooling step.
- Develop robust and self-stabilized HTS SMES magnets including high-performance electrical insulation with low-cost manufacturing and winding methods. Modular approaches and methods for up-scaling must be considered.
- Demonstrate HTS SMES system performance in attractive applications with long term field tests. From this, promising business cases need to be further developed and first niche markets need to be addressed.
- Explore the opportunities of hybrid SMES systems at different TRL levels depending on the maturity of the hybrid system, ranging from system studies up to first demonstrations.

Potential

Design flexibility
Long cycle life and lifetime
Capacity scalability
Recyclability

Barriers

Emerging technology
High investment costs
BoP complexity

Challenges

Increase energy density
Increase round-trip efficiency
Reduce cost
Improve cooling system

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